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Kelley et al.

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(45) **Date of Patent: Jan. 17, 2012**

(54) **GEOSPATIAL MODELING SYSTEM PROVIDING INPAINTING AND ERROR CALCULATION FEATURES AND RELATED METHODS**

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(73) Assignee: **Harris Corporation**, Melbourne, FL (US)

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(22) Filed: **Sep. 28, 2007**

(65) **Prior Publication Data**

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(51) **Int. Cl.**
G06G 7/48 (2006.01)

(52) **U.S. Cl.** **703/6**; 703/2

(58) **Field of Classification Search** 703/1, 2, 703/6

See application file for complete search history.

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Grohman et al., *Filling SRTM Voids: The Delta Surface Fill Model*, Photogrammetric Engineering and Remote Sensing, Mar. 2006, pp. 213-216.

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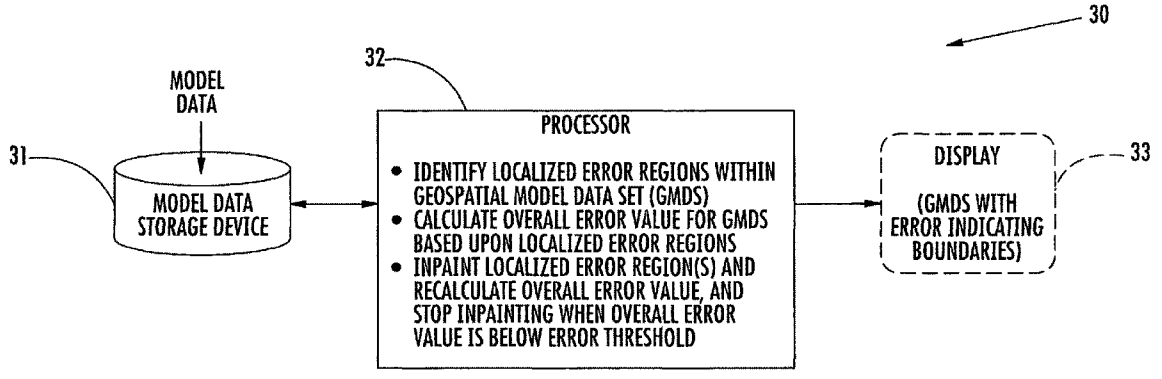
Primary Examiner — Kamini S Shah
Assistant Examiner — Herng-Der Day
(74) *Attorney, Agent, or Firm* — Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

(57) **ABSTRACT**

A geospatial modeling system may include a geospatial model data storage device and a processor. The processor may cooperate with the geospatial model data storage device for identifying a plurality of localized error regions within a geospatial model data set, calculating an overall error value for the geospatial model data set, and inpainting at least one of the localized error regions and re-calculating the overall error value, and stopping inpainting when the overall error value is below an error threshold.

15 Claims, 15 Drawing Sheets


30
32
MODEL DATA
31
MODEL DATA STORAGE DEVICE
PROCESSOR
• IDENTIFY LOCALIZED ERROR REGIONS WITHIN GEOSPATIAL MODEL DATA SET (GMDS)
• CALCULATE OVERALL ERROR VALUE FOR GMDS BASED UPON LOCALIZED ERROR REGIONS
• INPAINT LOCALIZED ERROR REGION(S) AND RECALCULATE OVERALL ERROR VALUE, AND STOP INPAINTING WHEN OVERALL ERROR VALUE IS BELOW ERROR THRESHOLD
DISPLAY
(GMDS WITH ERROR INDICATING BOUNDARIES)
33

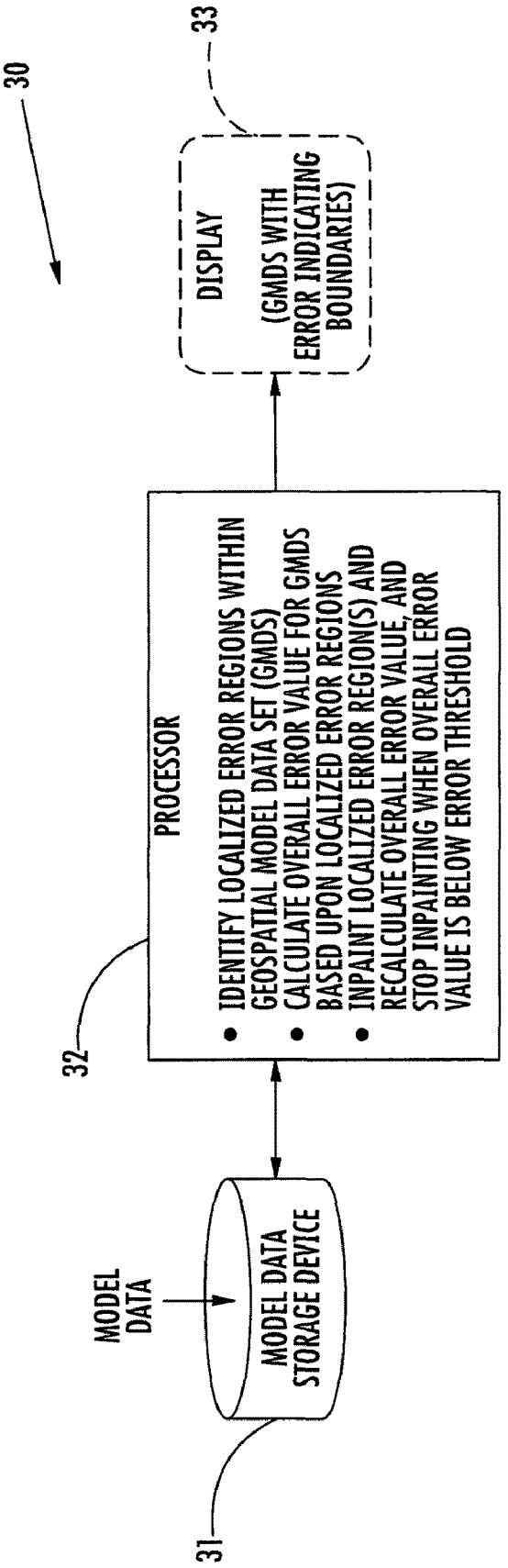

30
33
DISPLAY
(GMDS WITH ERROR INDICATING BOUNDARIES)
PROCESSOR
• IDENTIFY LOCALIZED ERROR REGIONS WITHIN GEOSPATIAL MODEL DATA SET (GMDS)
• CALCULATE OVERALL ERROR VALUE FOR GMDS BASED UPON LOCALIZED ERROR REGIONS
• INPAINT LOCALIZED ERROR REGION(S) AND RECALCULATE OVERALL ERROR VALUE, AND STOP INPAINTING WHEN OVERALL ERROR VALUE IS BELOW ERROR THRESHOLD
32
MODEL DATA
MODEL DATA STORAGE DEVICE
31

FIG. 1

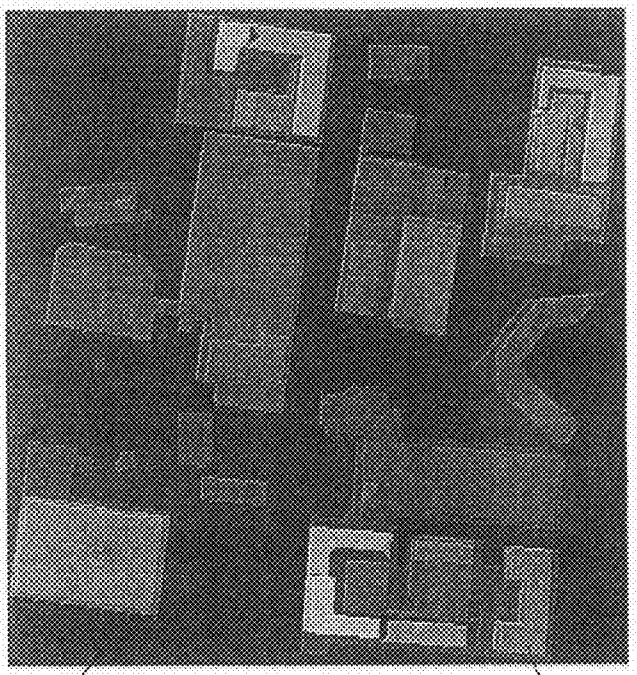


FIG. 2

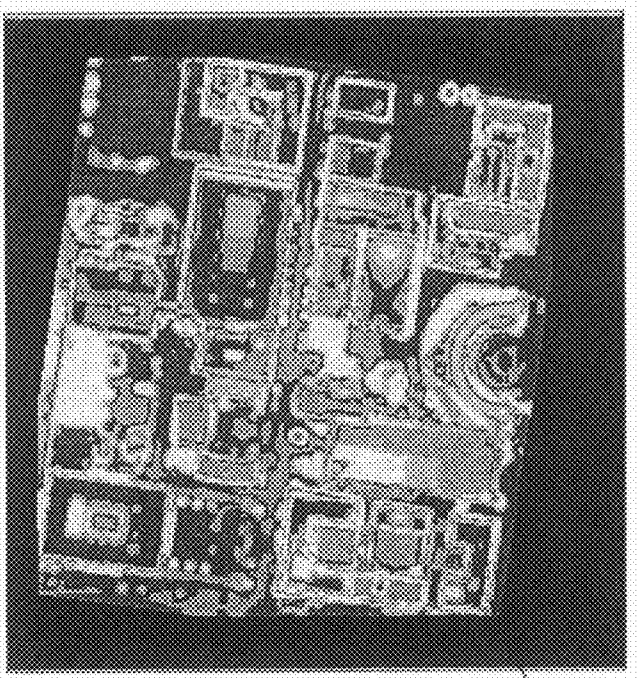


FIG. 3

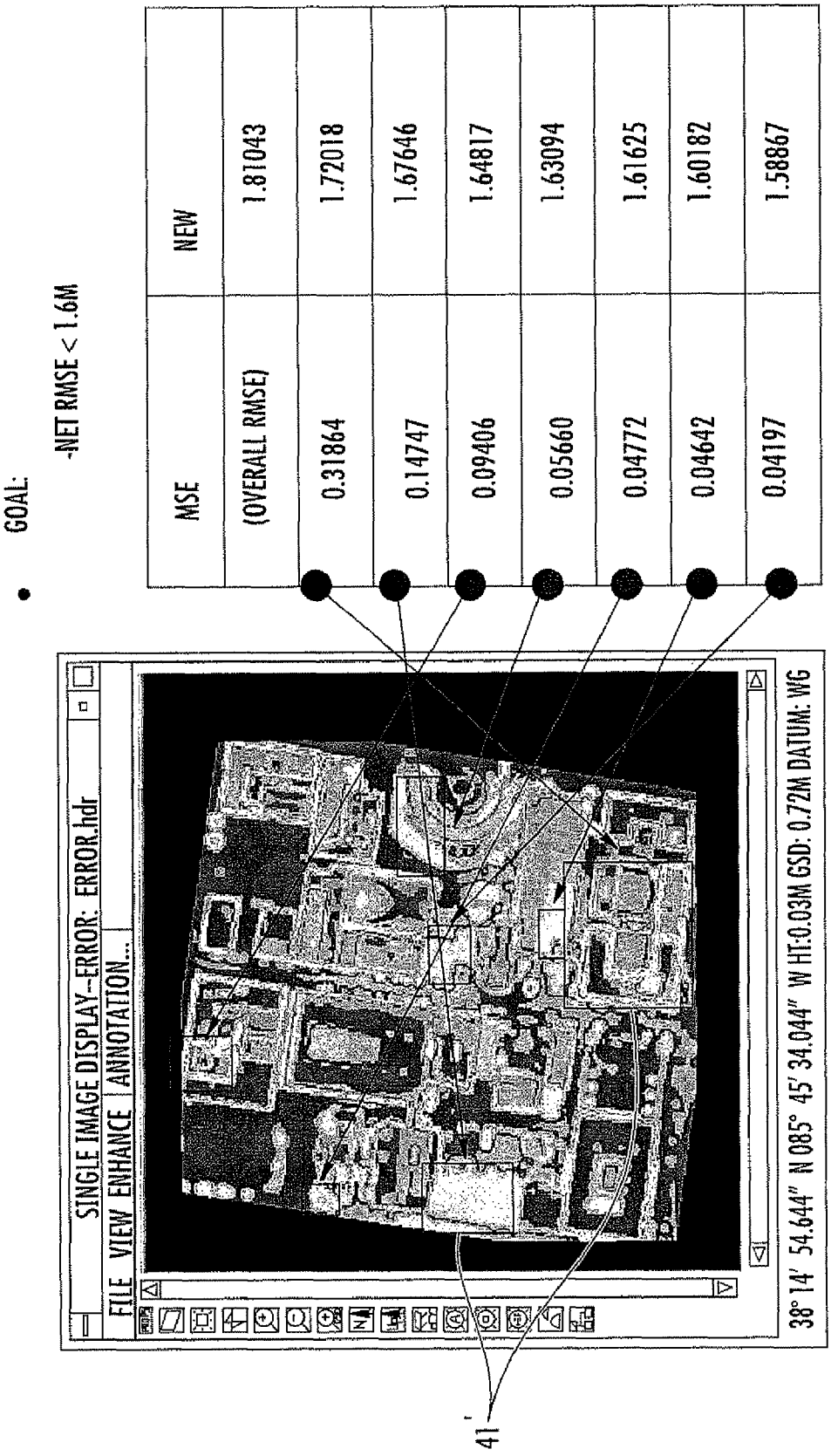

GOAL:
-NET RMSE < 1.6M
MSE
(OVERALL RMSE)
NEW
0.31864
1.81043
0.14747
1.72018
0.09406
1.67646
0.05660
1.64817
0.04772
1.63094
0.04642
1.61625
0.04197
1.60182
1.58867
SINGLE IMAGE DISPLAY--ERROR: ERROR.hdr
FILE VIEW ENHANCE ANNOTATION...
38° 14' 54.644" N 085° 45' 34.044" W HT:0.03M GSD: 0.72M DATUM: WG
41

FIG. 4

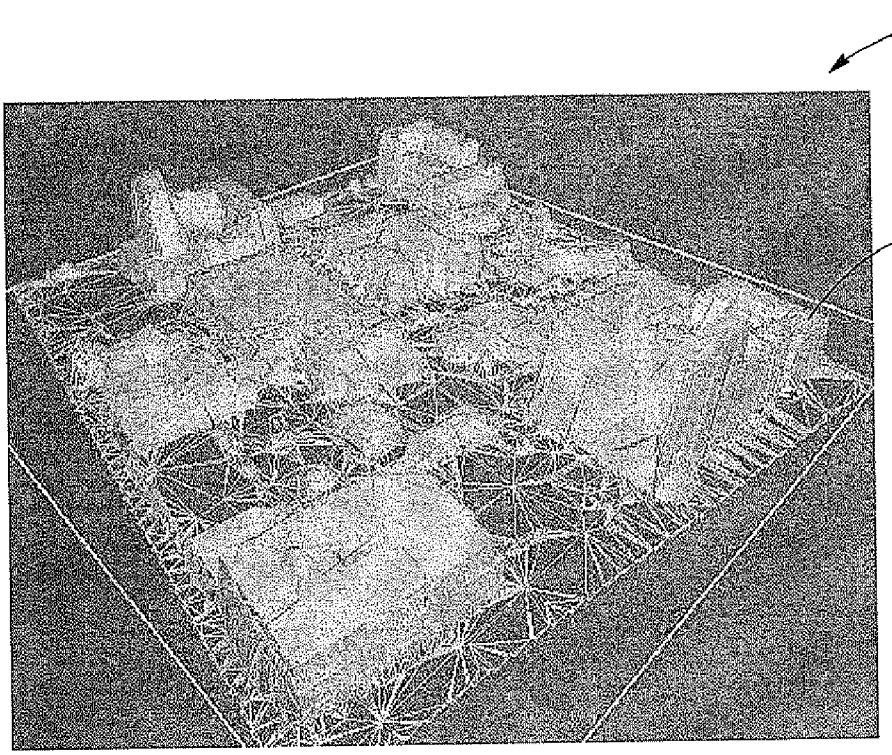


FIG. 5A

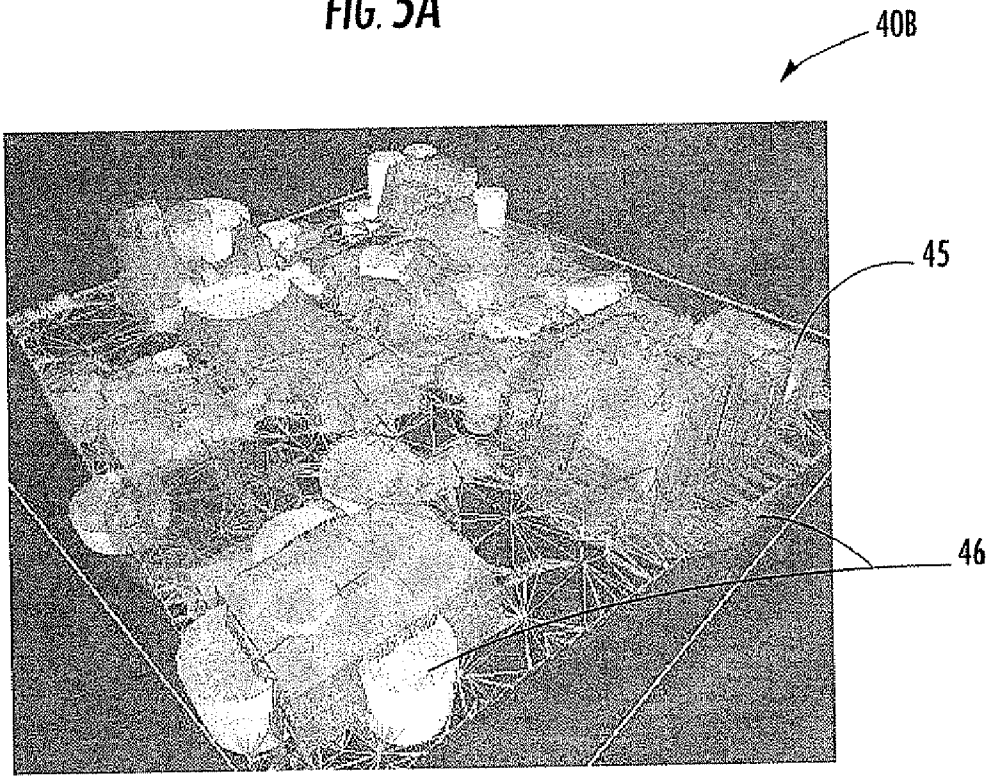


FIG. 5B

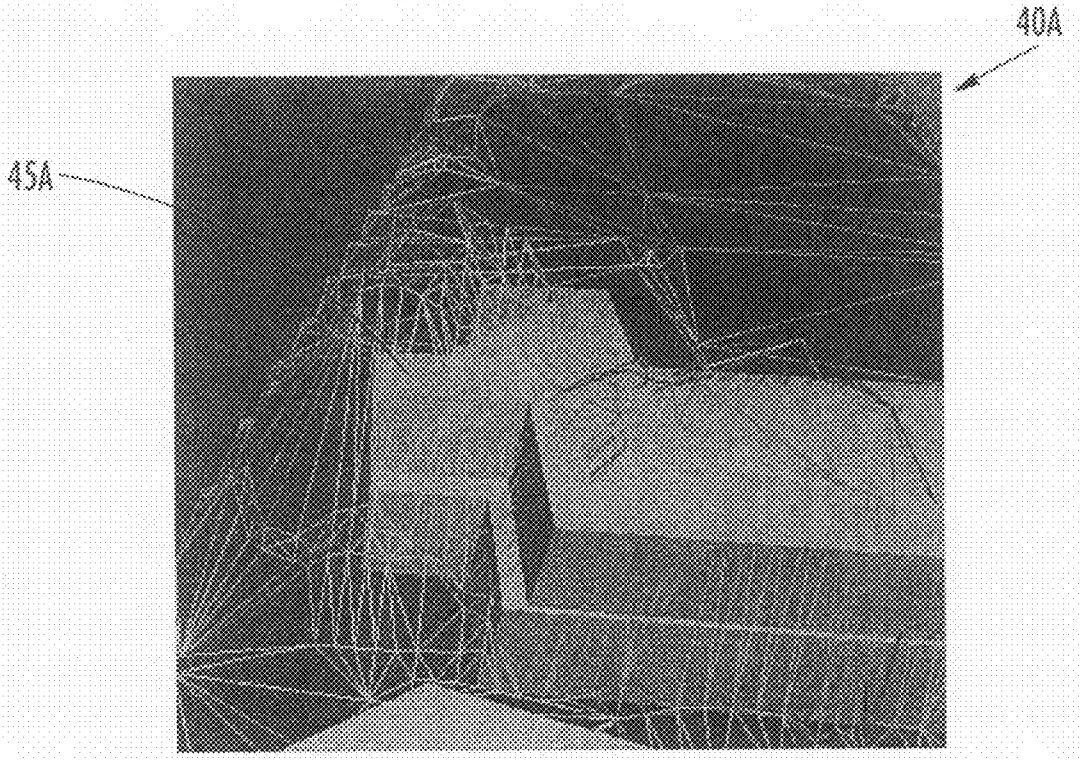


FIG. 6A

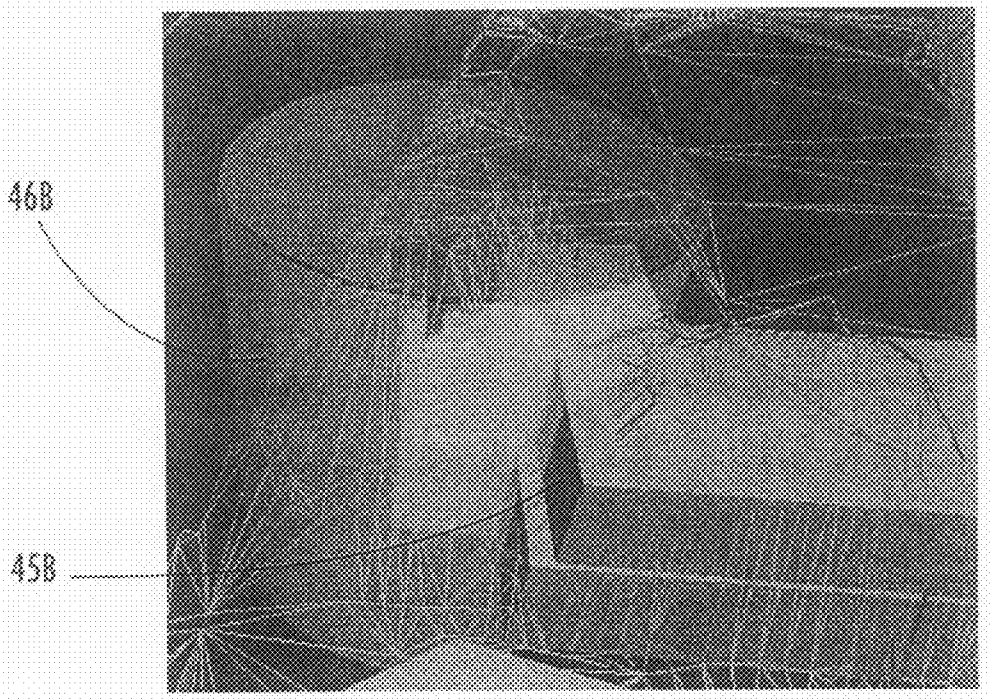


FIG. 6B

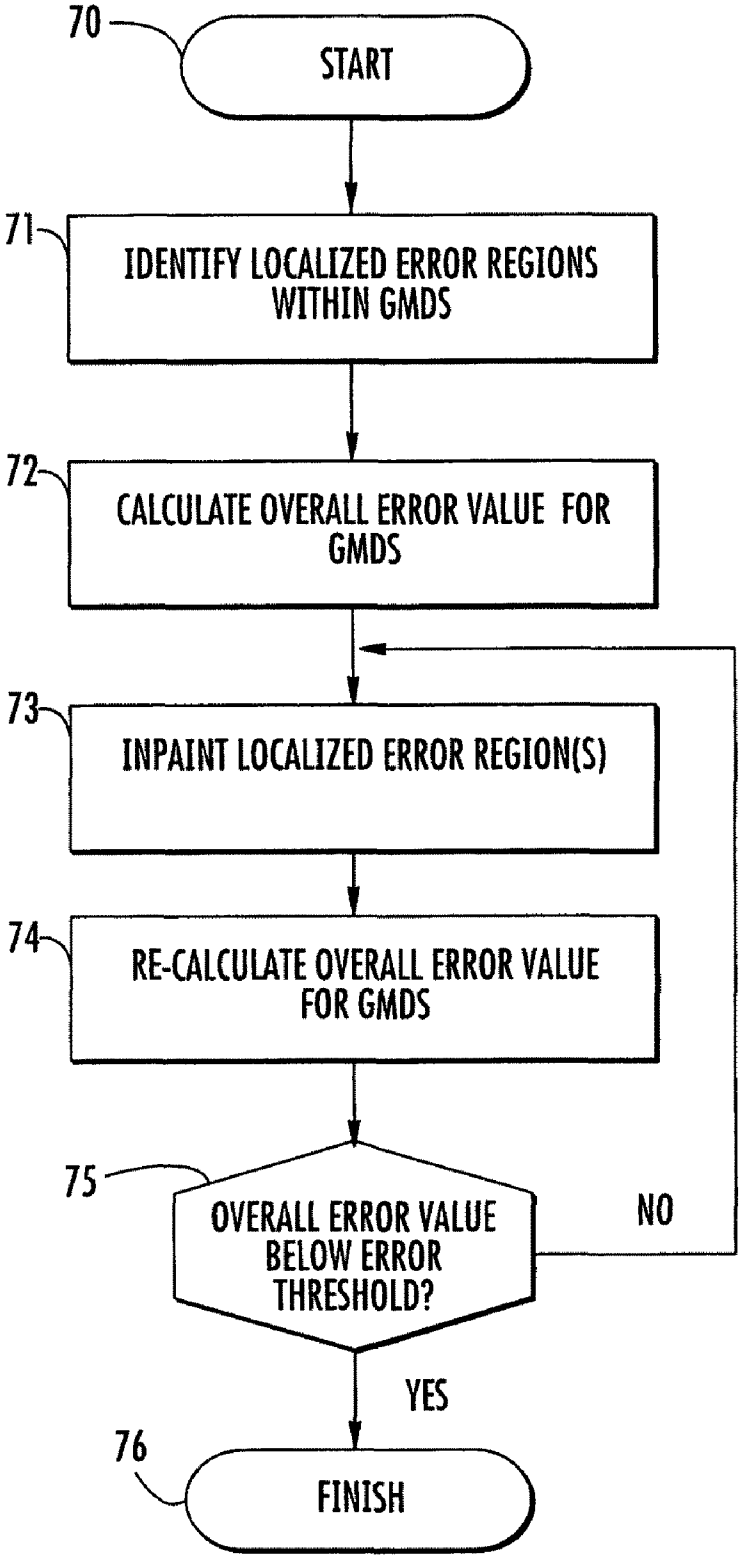

70
START
71
IDENTIFY LOCALIZED ERROR REGIONS WITHIN GMDS
72
CALCULATE OVERALL ERROR VALUE FOR GMDS
73
INPAINT LOCALIZED ERROR REGION(S)
74
RE-CALCULATE OVERALL ERROR VALUE FOR GMDS
75
OVERALL ERROR VALUE BELOW ERROR THRESHOLD?
NO
YES
76
FINISH

FIG. 7

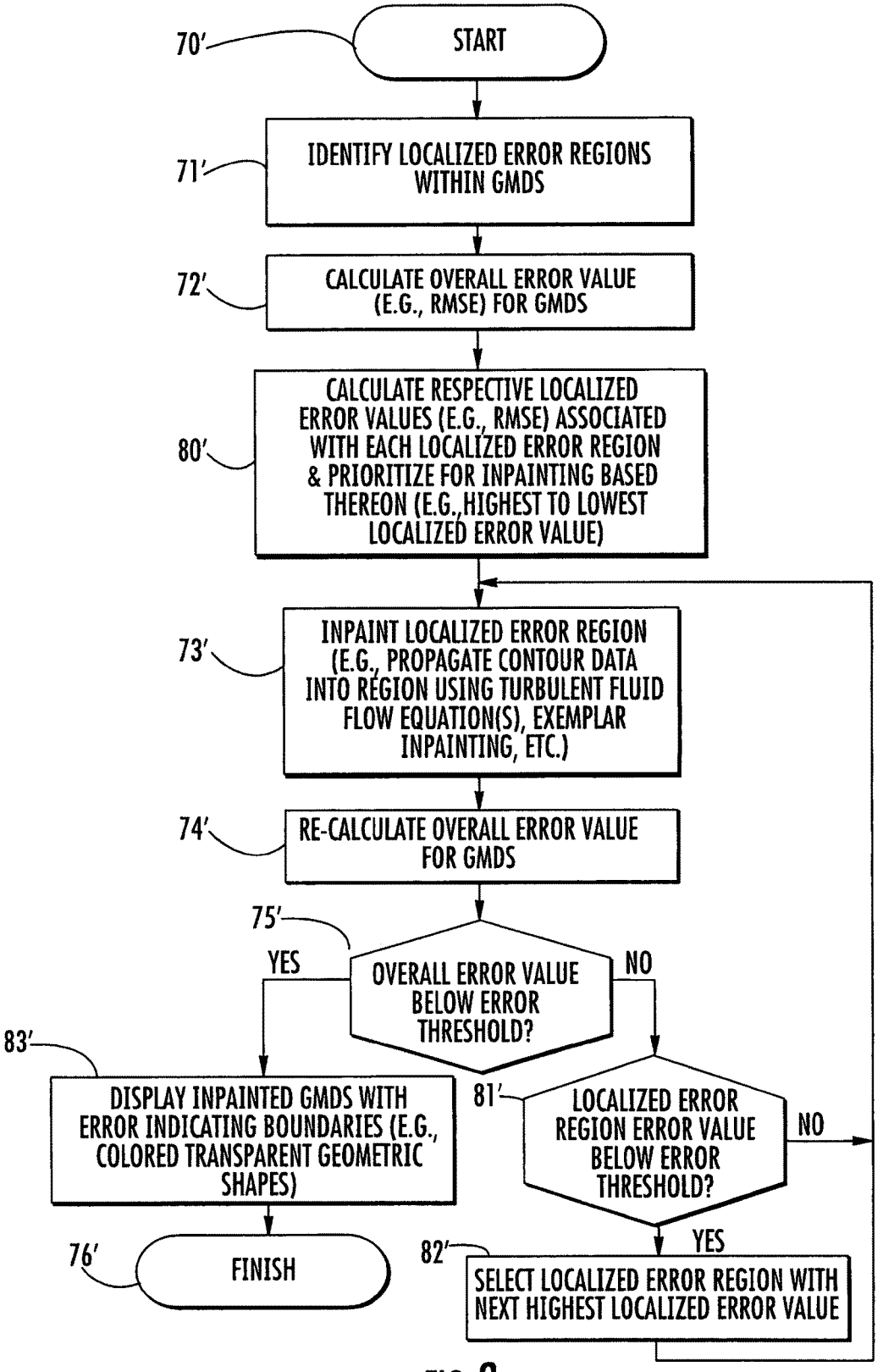

70'
START
71'
IDENTIFY LOCALIZED ERROR REGIONS WITHIN GMDS
72'
CALCULATE OVERALL ERROR VALUE (E.G., RMSE) FOR GMDS
80'
CALCULATE RESPECTIVE LOCALIZED ERROR VALUES (E.G., RMSE) ASSOCIATED WITH EACH LOCALIZED ERROR REGION & PRIORITIZE FOR INPAINTING BASED THEREON (E.G., HIGHEST TO LOWEST LOCALIZED ERROR VALUE)
73'
INPAINT LOCALIZED ERROR REGION (E.G., PROPAGATE CONTOUR DATA INTO REGION USING TURBULENT FLUID FLOW EQUATION(S), EXEMPLAR INPAINTING, ETC.)
74'
RE-CALCULATE OVERALL ERROR VALUE FOR GMDS
75'
OVERALL ERROR VALUE BELOW ERROR THRESHOLD?
YES
NO
83'
DISPLAY INPAINTED GMDS WITH ERROR INDICATING BOUNDARIES (E.G., COLORED TRANSPARENT GEOMETRIC SHAPES)
81'
LOCALIZED ERROR REGION ERROR VALUE BELOW ERROR THRESHOLD?
NO
YES
76'
FINISH
82'
SELECT LOCALIZED ERROR REGION WITH NEXT HIGHEST LOCALIZED ERROR VALUE

FIG. 8

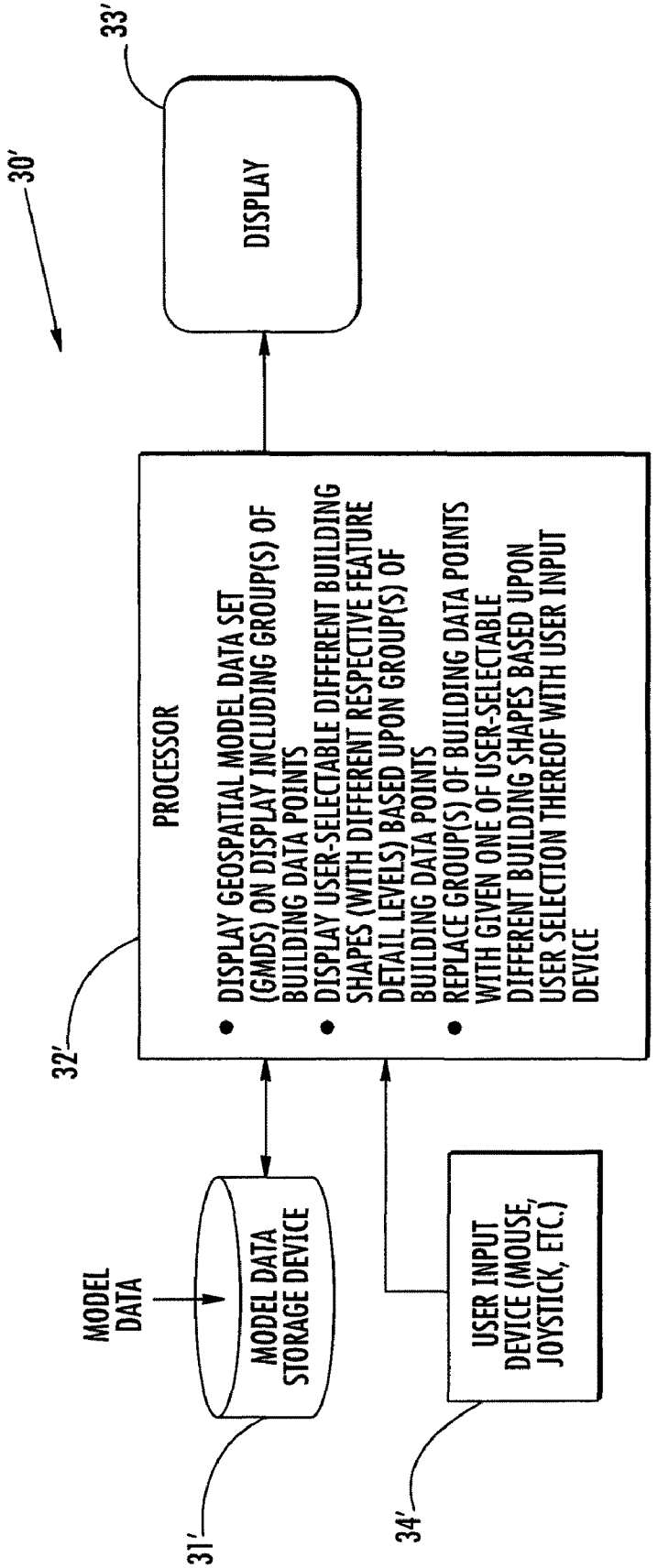

30'
33'
DISPLAY
PROCESSOR
• DISPLAY GEOSPATIAL MODEL DATA SET (GMDS) ON DISPLAY INCLUDING GROUP(S) OF BUILDING DATA POINTS
• DISPLAY USER-SELECTABLE DIFFERENT BUILDING SHAPES (WITH DIFFERENT RESPECTIVE FEATURE DETAIL LEVELS) BASED UPON GROUP(S) OF BUILDING DATA POINTS
• REPLACE GROUP(S) OF BUILDING DATA POINTS WITH GIVEN ONE OF USER-SELECTABLE DIFFERENT BUILDING SHAPES BASED UPON USER SELECTION THEREOF WITH USER INPUT DEVICE
32'
MODEL DATA
MODEL DATA STORAGE DEVICE
31'
USER INPUT DEVICE (MOUSE, JOYSTICK, ETC.)
34'

FIG. 9

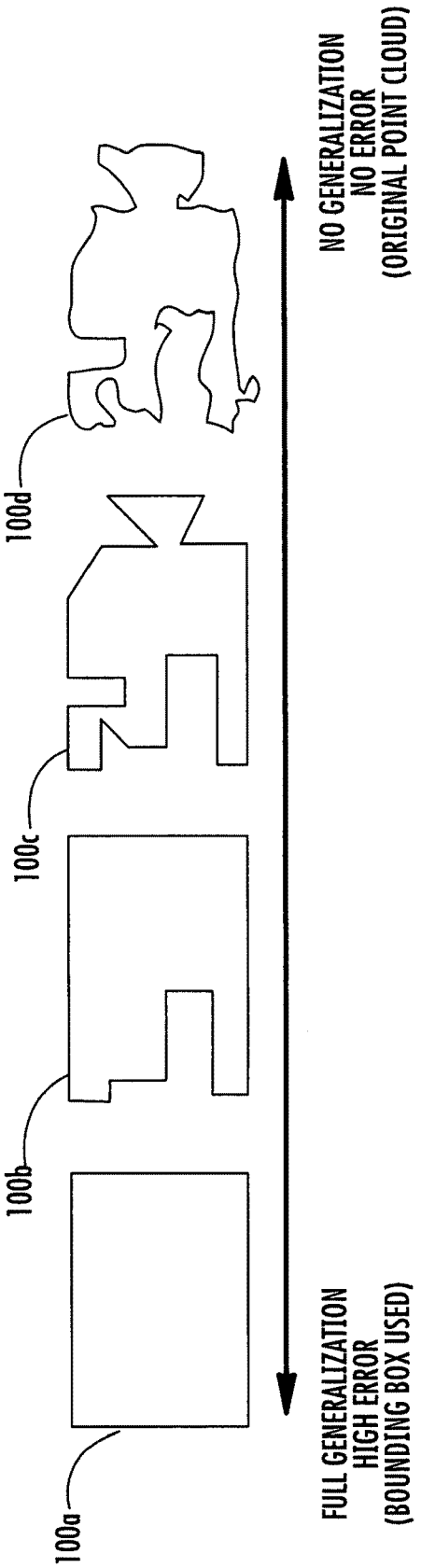

NO GENERALIZATION
NO ERROR
(ORIGINAL POINT CLOUD)
100d
100c
100b
100a
FULL GENERALIZATION
HIGH ERROR
(BOUNDING BOX USED)

FIG. 10

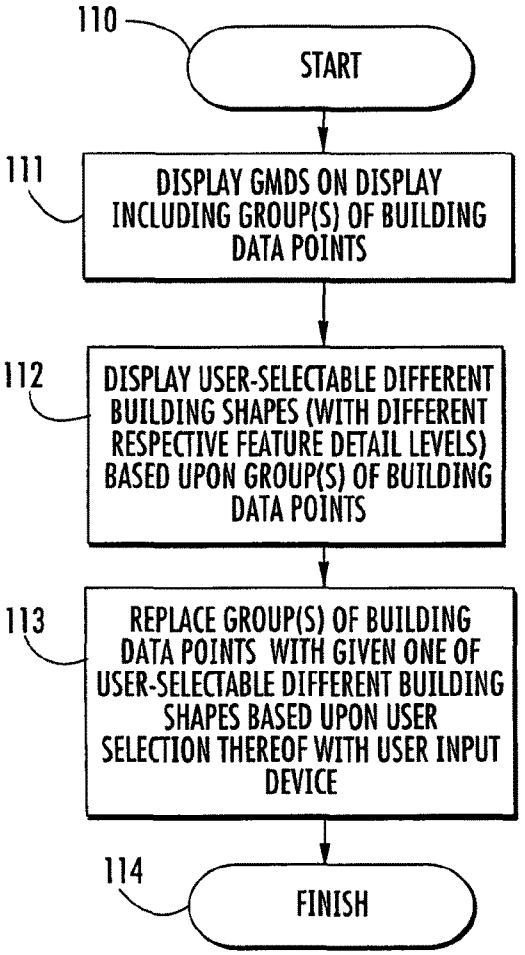

110
START
111
DISPLAY GMDS ON DISPLAY INCLUDING GROUP(S) OF BUILDING DATA POINTS
112
DISPLAY USER-SELECTABLE DIFFERENT BUILDING SHAPES (WITH DIFFERENT RESPECTIVE FEATURE DETAIL LEVELS) BASED UPON GROUP(S) OF BUILDING DATA POINTS
113
REPLACE GROUP(S) OF BUILDING DATA POINTS WITH GIVEN ONE OF USER-SELECTABLE DIFFERENT BUILDING SHAPES BASED UPON USER SELECTION THEREOF WITH USER INPUT DEVICE
114
FINISH

FIG. 11

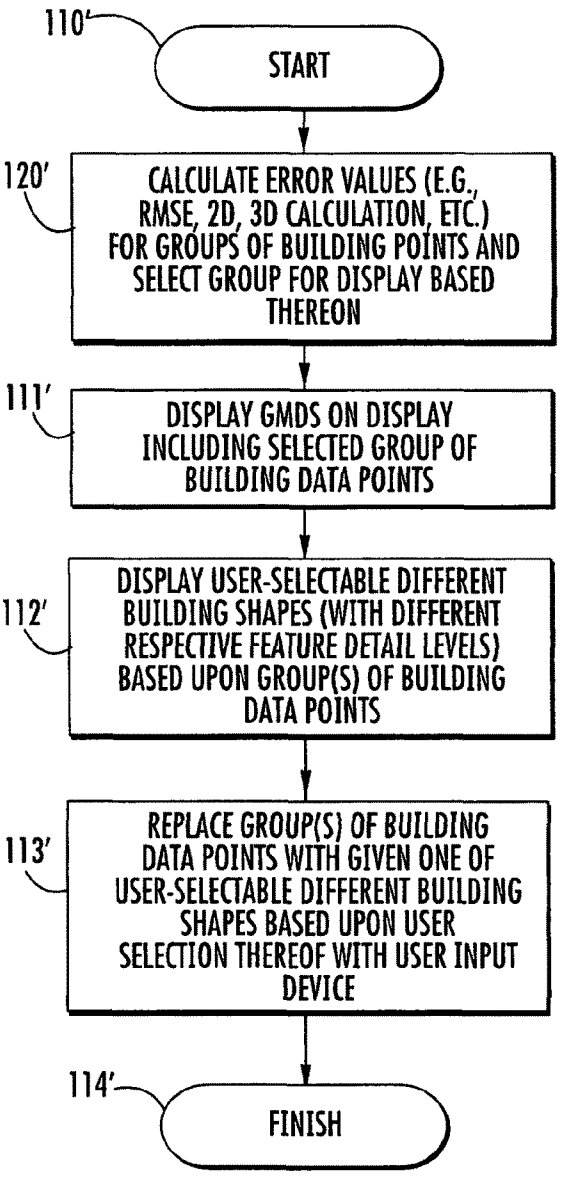

110'
START
120'
CALCULATE ERROR VALUES (E.G., RMSE, 2D, 3D CALCULATION, ETC.) FOR GROUPS OF BUILDING POINTS AND SELECT GROUP FOR DISPLAY BASED THEREON
111'
DISPLAY GMDS ON DISPLAY INCLUDING SELECTED GROUP OF BUILDING DATA POINTS
112'
DISPLAY USER-SELECTABLE DIFFERENT BUILDING SHAPES (WITH DIFFERENT RESPECTIVE FEATURE DETAIL LEVELS) BASED UPON GROUP(S) OF BUILDING DATA POINTS
113'
REPLACE GROUP(S) OF BUILDING DATA POINTS WITH GIVEN ONE OF USER-SELECTABLE DIFFERENT BUILDING SHAPES BASED UPON USER SELECTION THEREOF WITH USER INPUT DEVICE
114'
FINISH

FIG. 12

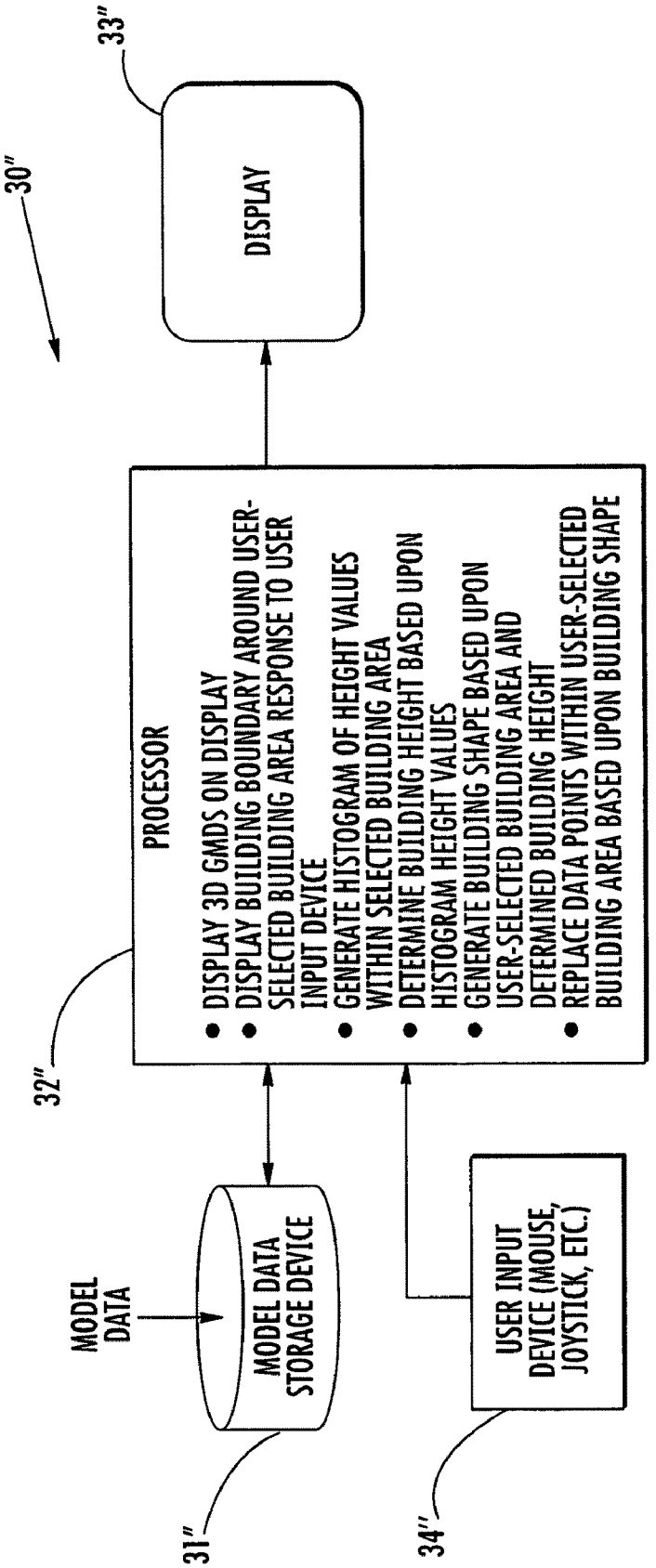

30″
33″
DISPLAY
PROCESSOR
• DISPLAY 3D GMDS ON DISPLAY
• DISPLAY BUILDING BOUNDARY AROUND USER-SELECTED BUILDING AREA RESPONSE TO USER INPUT DEVICE
• GENERATE HISTOGRAM OF HEIGHT VALUES WITHIN SELECTED BUILDING AREA
• DETERMINE BUILDING HEIGHT BASED UPON HISTOGRAM HEIGHT VALUES
• GENERATE BUILDING SHAPE BASED UPON USER-SELECTED BUILDING AREA AND DETERMINED BUILDING HEIGHT
• REPLACE DATA POINTS WITHIN USER-SELECTED BUILDING AREA BASED UPON BUILDING SHAPE
32″
MODEL DATA
MODEL DATA STORAGE DEVICE
31″
USER INPUT DEVICE (MOUSE, JOYSTICK, ETC.)
34″

FIG. 13

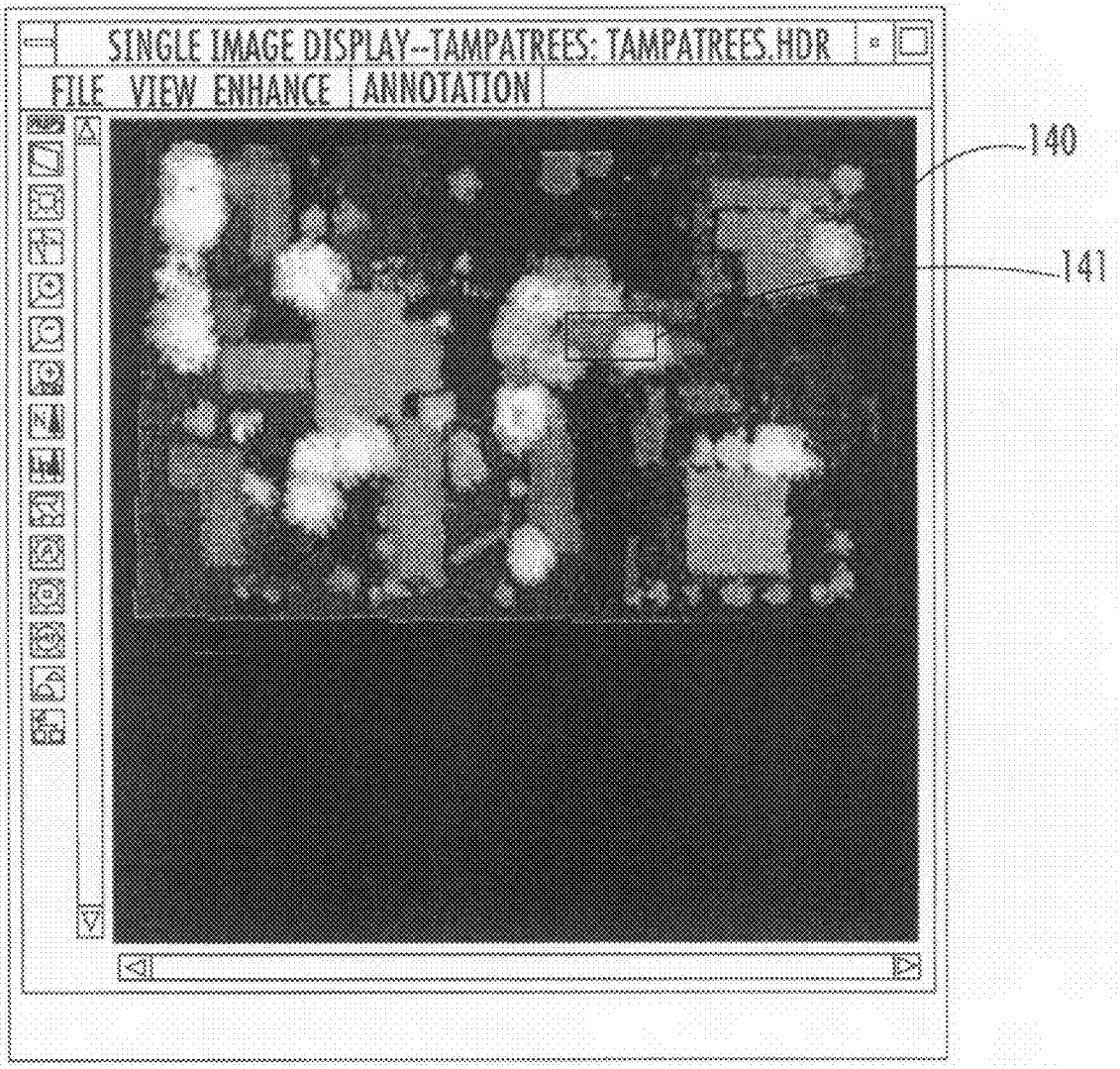

SINGLE IMAGE DISPLAY--TAMPATREES: TAMPATREES.HDR
FILE VIEW ENHANCE ANNOTATION
140
141

FIG. 14

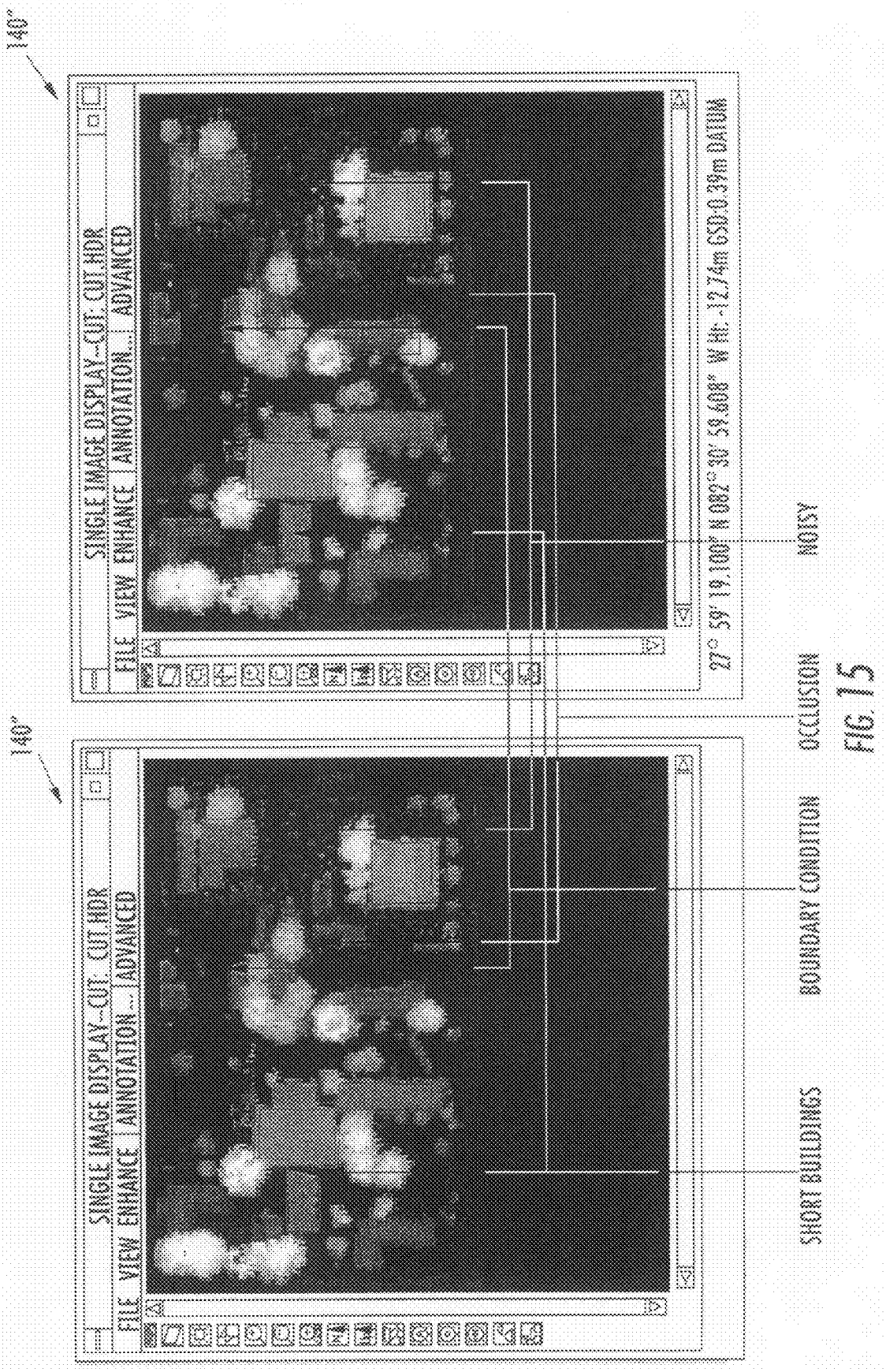

140"
SINGLE IMAGE DISPLAY--CUT_CUT.HDR
FILE VIEW ENHANCE ANNOTATION... ADVANCED
27° 59' 19.160" N 082° 30' 59.608" W Ht: -12.74m GSD:0.39m DATUM
NOISY
OCCLUSION
140"
SINGLE IMAGE DISPLAY--CUT_CUT.HDR
FILE VIEW ENHANCE ANNOTATION... ADVANCED
BOUNDARY CONDITION
SHORT BUILDINGS

FIG. 15

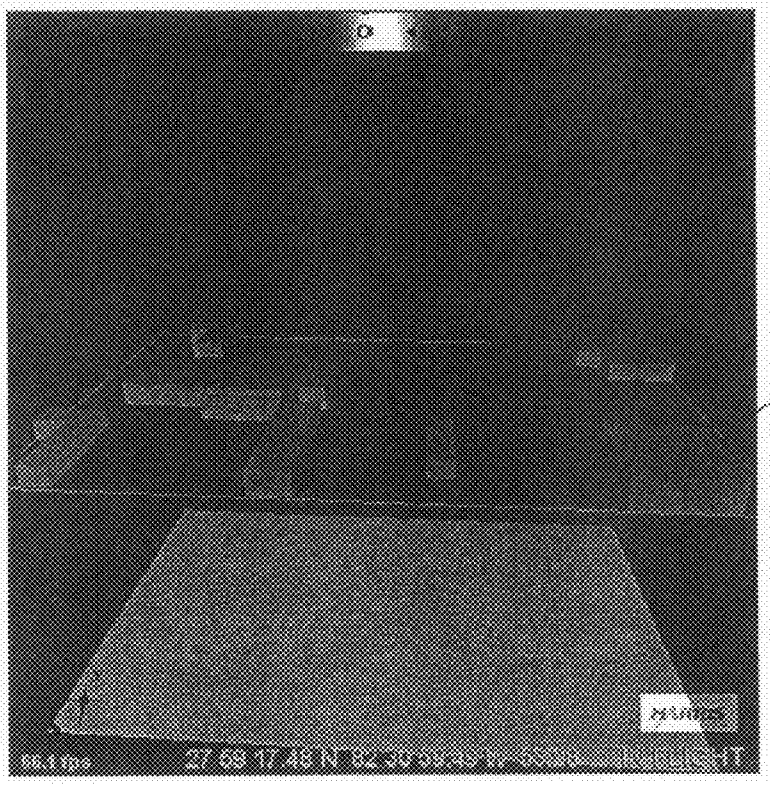


FIG. 16A

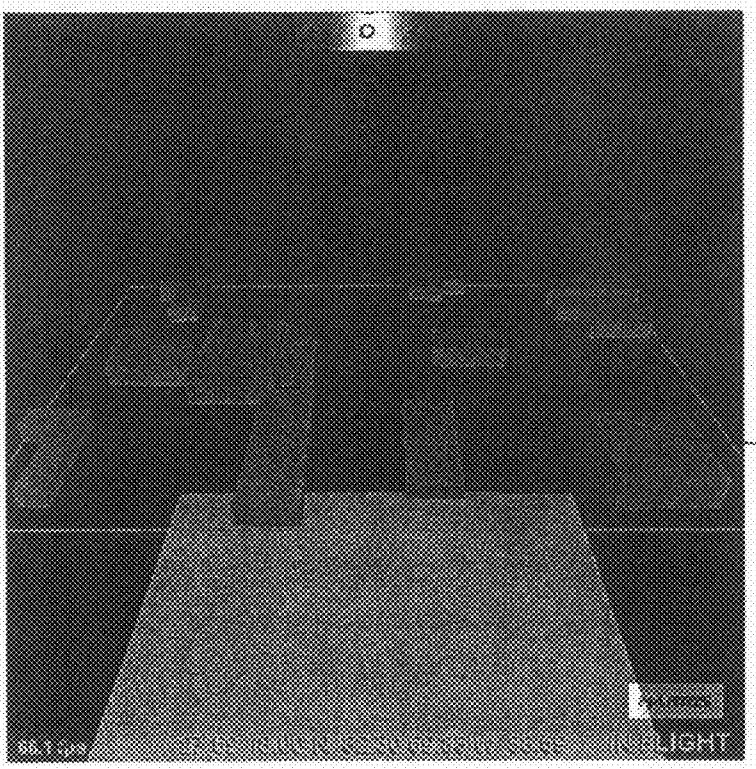


FIG. 16B

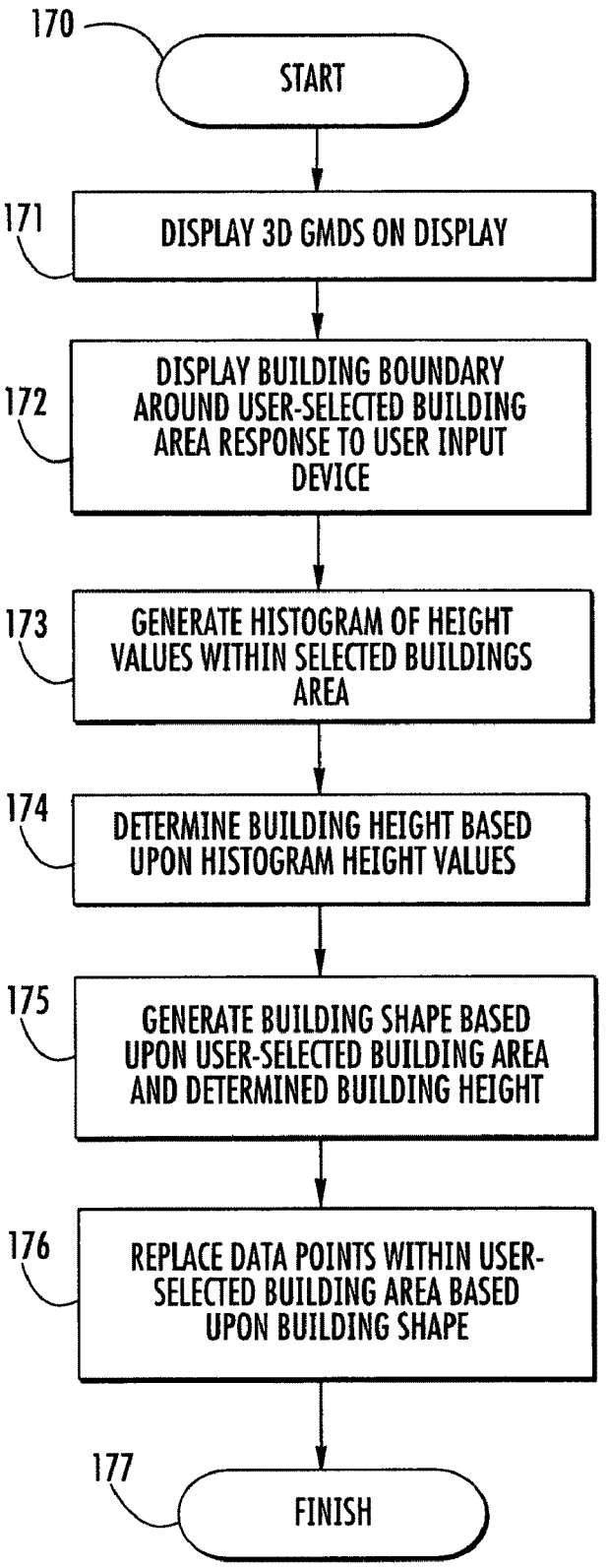

170
START
171
DISPLAY 3D GMDS ON DISPLAY
172
DISPLAY BUILDING BOUNDARY AROUND USER-SELECTED BUILDING AREA RESPONSE TO USER INPUT DEVICE
173
GENERATE HISTOGRAM OF HEIGHT VALUES WITHIN SELECTED BUILDINGS AREA
174
DETERMINE BUILDING HEIGHT BASED UPON HISTOGRAM HEIGHT VALUES
175
GENERATE BUILDING SHAPE BASED UPON USER-SELECTED BUILDING AREA AND DETERMINED BUILDING HEIGHT
176
REPLACE DATA POINTS WITHIN USER-SELECTED BUILDING AREA BASED UPON BUILDING SHAPE
177
FINISH

FIG. 17

GEOSPATIAL MODELING SYSTEM PROVIDING INPAINTING AND ERROR CALCULATION FEATURES AND RELATED METHODS

FIELD OF THE INVENTION

The present invention relates to the field of data modeling, and, more particularly, to modeling systems such as geospatial modeling systems and related methods.

BACKGROUND OF THE INVENTION

Topographical models of geographical areas may be used for many applications. For example, topographical models may be used in flight simulators and for planning military missions. Furthermore, topographical models of man-made structures (e.g., cities) may be extremely helpful in applications such as cellular antenna placement, urban planning, disaster preparedness and analysis, and mapping, for example.

Various types and methods for making topographical models are presently being used. One common topographical model is the digital elevation map (DEM). A DEM is a sampled matrix representation of a geographical area which may be generated in an automated fashion by a computer. In a DEM, coordinate points are made to correspond with a height value. DEMs are typically used for modeling terrain where the transitions between different elevations (e.g., valleys, mountains, etc.) are generally smooth from one to a next. That is, DEMs typically model terrain as a plurality of curved surfaces and any discontinuities therebetween are thus "smoothed" over. Thus, in a typical DEM no distinct objects are present on the terrain.

One particularly advantageous 3D site modeling product is RealSite® from the present Assignee Harris Corp. RealSite® may be used to register overlapping images of a geographical area of interest, and extract high resolution DEMs using stereo and nadir view techniques. RealSite® provides a semi-automated process for making three-dimensional (3D) topographical models of geographical areas, including cities, that have accurate textures and structure boundaries. Moreover, RealSite® models are geospatially accurate. That is, the location of any given point within the model corresponds to an actual location in the geographical area with very high accuracy. The data used to generate RealSite® models may include aerial and satellite photography, electro-optical, infrared, and light detection and ranging (LIDAR), for example.

Another similar system from Harris Corp. is LiteSite®. LiteSite® models provide automatic extraction of ground, foliage, and urban digital elevation models (DEMs) from LIDAR and IFSAR imagery. LiteSite™ can be used to produce affordable, geospatially accurate, high-resolution 3-D models of buildings and terrain.

U.S. Pat. No. 6,654,690 to Rahmes et al., which is also assigned to the present Assignee and is hereby incorporated herein in its entirety by reference, discloses an automated method for making a topographical model of an area including terrain and buildings thereon based upon randomly spaced data of elevation versus position. The method includes processing the randomly spaced data to generate gridded data of elevation versus position conforming to a predetermined position grid, processing the gridded data to distinguish building data from terrain data, and performing polygon extraction for the building data to make the topographical model of the area including terrain and buildings thereon.

In many instances there will be voids or gaps in the data used to generate a geospatial or other model. The voids negatively affect the quality of the resulting model, and thus it is desirable to compensate for these voids while processing the data, if possible. Various interpolation techniques are generally used for filling in missing data in a data field. One such technique is sinc interpolation, which assumes that a signal is band-limited. While this approach is well suited for communication and audio signals, it may not be well suited for 3D data models. Another approach is polynomial interpolation. This approach is sometimes difficult to implement because the computational overhead may become overly burdensome for higher order polynomials, which may be necessary to provide desired accuracy.

One additional interpolation approach is spline interpolation. While this approach may provide a relatively high reconstruction accuracy, this approach may be problematic to implement in a 3D data model because of the difficulty in solving a global spline over the entire model, and because the required matrices may be ill-conditioned. One further drawback of such conventional-techniques is that they tend to blur edge content, which may be a significant problem in a 3D topographical model.

Another approach for filling in regions within an image is set forth in U.S. Pat. No. 6,987,520 to Criminisi et al. This patent discloses an exemplar-based filling system which identifies appropriate filling material to replace a destination region in an image and fills the destination region using this material. This is done to alleviate or minimize the amount of manual editing required to fill a destination region in an image. Tiles of image data are "borrowed" from the proximity of the destination region or some other source to generate new image data to fill in the region. Destination regions may be designated by user input (e.g., selection of an image region by a user) or by other means (e.g., specification of a color or feature to be replaced). In addition, the order in which the destination region is filled by example tiles may be configured to emphasize the continuity of linear structures and composite textures using a type of isophote-driven image-sampling process.

With respect to geospatial models such as DEMs, various approaches have been attempted to address error recognition and correction due to voids, etc. One such approach is set forth in an article by Gousie entitled "Digital Elevation Model Error Detection and Visualization," 4th ISPRS Workshop on Dynamic & Multi-dimensional GIS (Pontypridd, Wales, UK, 2005), C. Gold, Ed., pp. 42-46. This paper presents two methods for visualizing errors in a DEM. One method begins with a root mean square error (RMSE) and then highlights areas in the DEM that contain errors beyond a threshold. A second method computes local curvature and displays discrepancies in the DEM. The visualization methods are in three dimensions and are dynamic, giving the viewer the option of rotating the surface to inspect any portion at any angle.

Another example is set forth in an article by Grohman et al. entitled "Filling SRTM Voids: The Delta Surface Fill Method," Photogrammetric Engineering & Remote Sensing, March 2006, pp. 213-216. This article discusses a technique for fillings voids in SRTM digital elevation data is that is intended to provide an improvement over traditional approaches, such as the Fill and Feather (F&F) method. In the F&F approach, a void is replaced with the most accurate digital elevation source ("fill") available with the void-specific perimeter bias removed. Then the interface is feathered into the SRTM, smoothing the transition to mitigate any abrupt change. It works optimally when the two surfaces are very close together and separated by only a bias with minimal

topographic variance. The Delta Surface Fill (DSF) process replaces the void with fill source posts that are adjusted to the SRTM values found at the void interface. This process causes the fill to more closely emulate the original SRTM surface while still retaining the useful data the fill contains.

Despite the advantages such prior art approaches may provide in certain applications, further advancements may be desirable for error detection and correction in geospatial and other model data.

SUMMARY OF THE INVENTION

In view of the foregoing background, it is therefore an object of the present invention to provide a geospatial modeling system providing enhanced error detection and correction features and related methods.

This and other objects, features, and advantages are provided by a geospatial modeling system which may include a geospatial model data storage device and a processor. The processor may cooperate with the geospatial model data storage device for identifying a plurality of localized error regions within a geospatial model data set, calculating an overall error value for the geospatial model data set, and inpainting at least one of the localized error regions and re-calculating the overall error value. Inpainting may be stopped when the overall error value is below an error threshold.

More particularly, the processor may further determine respective localized error values associated with each localized error region, and prioritize the localized error regions for inpainting based upon their respective localized error regions. By way of example, the processor may prioritize the localized error regions from highest to lowest localized error values. Furthermore, the processor may iteratively inpaint the localized region with the highest localized error value until the localized error value is below the error threshold, and, if the overall error value is not below the error threshold, then the processor may iteratively inpaint the localized error region with the next highest localized error value.

The geospatial modeling system may further comprise a display. As such, the processor may cooperate with the geospatial model data storage device and the display to display the geospatial model data set along with error indicating boundaries indicating the localized error regions. By way of example, the error indicating boundaries may comprise colored transparent geometric shapes. In addition, each localized error value may comprise a localized root mean square error (RMSE) value, and the overall error value may comprise an overall root mean square error (RMSE) value.

The inpainting may comprise iteratively propagating contour data from outside the at least one localized error region into the at least one localized error region. By way of example, this may be done based upon at least one turbulent fluid flow modeling equation, as well as based upon exemplar inpainting.

A geospatial modeling method aspect may include identifying a plurality of localized error regions within a geospatial model data set, and calculating an overall error value for the geospatial model data set based upon the localized error regions. The method may further include iteratively inpainting at least one of the localized error regions and re-calculating the overall error value, and stopping inpainting when the overall error value is below an error threshold.

A computer-readable medium may have computer-executable instructions for causing a computer to perform steps comprising identifying a plurality of localized error regions within a geospatial model data set, and calculating an overall error value for the geospatial model data set based upon the localized error regions. The steps may further include iteratively inpainting at least one of the localized error regions and re-calculating the overall error value, and stopping inpainting when the overall error value is below an error threshold.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic block diagram of a geospatial modeling system in accordance with one exemplary embodiment.

FIGS. **2** and **3** are a digital elevation model (DEM) and a corresponding error DEM for which the system of FIG. **1** performs error detection and correction.

FIG. **4** is a screen print of the error DEM of FIG. **3** and an associated table identifying relative errors of localized error regions.

FIGS. **5**A and **5**B are triangulated irregular network (TIN) representations of the DEM of FIG. **2** without and with error indicating boundaries indicating localized error regions, respectively.

FIGS. **6**A and **6**B are more detailed views of a portion of the TINs of FIGS. **5**A and **5**B, respectively.

FIGS. **7** and **8** are flow diagrams illustrating a geospatial modeling method for identifying and inpainting localized error regions in geospatial model data.

FIG. **9** is a schematic block diagram of an alternative embodiment of the system of FIG. **1** providing user-selectable building shape options.

FIG. **10** is a series of building shapes displayed by the system of FIG. **9**.

FIGS. **11** and **12** are flow diagrams illustrating an alternative geospatial modeling method for providing the user-selectable building shape options.

FIG. **13** is a schematic block diagram of yet another alternative embodiment of the system of FIG. **1** for generating building shapes based upon user-selected building areas and determined height values.

FIG. **14** is a screen print of a DEM with a building boundary area to be replaced with a generated building shape.

FIG. **15** is a comparison of screen prints for the DEM of FIG. **14** after fully automatic generation, and after being touched up through a manual/automated approach by the system of FIG. **13**.

FIGS. **16**A and **16**B are 3D display views of the DEMs of FIG. **15** for the fully automatic and the touched-up versions, respectively.

FIG. **17** is a flow diagram of another alternative embodiment of a geospatial modeling method for generating building shapes based upon user-selected building areas and determined height values.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and prime notation is used to indicate similar elements in alternate embodiments.

Referring initially to FIGS. **1-7**, a geospatial modeling system **30** illustratively includes a geospatial model data stor-

age device **31**, a processor **32**, and (optionally) a display **33**. The geospatial model data storage device **31** stores geospatial model data, such as digital elevation model (DEM), digital surface model (DSM), and/or triangulated irregular network (TTIN) data, for example. Generally speaking, such model data is generated from "raw" data captures, such as LIDAR, synthetic aperture radar (SAR), photography, electro-optical, infrared, etc., using systems such as the above-noted RealSite™ and LiteSite™ site modeling products, as will be appreciated by those skilled in the art. The geospatial model data set may be generated by another source and provided to the processor **32** for the additional processing operations to be described below, or the processor may generate the geospatial model data set in other embodiments.

By way of background, with typical prior art approaches, when automatically generating a 3D site model from a digital elevation model (DEM), for example, there is a usually a need for a manual (i.e., human operator) touch-up due to factors such as: noisy data; occlusion; boundary conditions (being partially cut off, etc.), algorithm limitations, etc. However, manual touch-up of site models, which can be very large, may be extremely time consuming. Moreover, locating the areas that require editing in large models may also be tedious and difficult.

The same issue presents itself in manual site model creation. Manual editing is a relatively long and expensive step in the production process, as a modeler (i.e., the user or operator) often has to render a model in 3D, locate the problem areas, find where these correlate to in 2D space, and then make the corrections in 2D image space. In particular, both manual model generation and manual touch-up of automated models typically rely upon images to produce a polygon. The polygon's height is obtained by calculation based upon cues in the image or relocating the polygon to another image. Location of the areas to be fixed is typically done completely by the modeler (i.e., "by eye"), and is dependent on his/her attention to detail. In other words, this introduces the possibility for user error.

As such, in both automated and manual processes, being able to find such problem areas in the model, and then having a relatively fast and effective approach to correct them with little or reduced operator effort may save a significant amount of time and cost. Therefore, in accordance with one aspect, the system **30** may advantageously perform enhanced error detection and correction operations.

More particularly, beginning at Block **70**, the processor **32** advantageously cooperates with the geospatial model data storage device **31** for identifying a plurality of localized error regions within a geospatial model data set, at Block **71**, and calculates an overall error value for the DEM **40'**, at Block **72**. An exemplary DEM **40** with errors therein is shown in FIG. **2**. An alternative error view **40'** of the DEM is shown in FIG. **3**, and specific localized error regions **41'** within the error DEM are shown in FIG. **4**. That is, the processor **30** advantageously separates areas within the DEM **40** having a relatively high error value from areas having a relatively low error value to determine the localized error regions **41'**. By way of example, the error values of localized error regions **41'** within the DEM **40**, as well as the overall DEM error value, may be calculated using various approaches, including a total error, local root mean square error (RMSE), a maximum error, a mean square error (MSE), MSE relative to the overall DEM, RMSE relative to the overall DEM, etc., as will be appreciated by those skilled in the art.

$$MSE = \frac{\sum_{i=1}^{n} (e_i - a_i)^2}{n}$$

$$RMSE = \sqrt{MSE}$$

$$MSE_{Group} = \frac{\sum_{i=1, i \in Group}^{n} (e_i - a_i)^2}{n}$$

$$RMSE_{Fixed} = \sqrt{MSE_{DEM} - \sum_{Group \in Fixed} MSE_{Group}}$$

The processor **32** further inpaints one or more of the of the localized error regions **41'** to repair or otherwise correct missing, obscured, etc., portions thereof, at Block **73**. More particularly, this may be done by propagating contour data from outside a given localized error region **41'** into the region, as will be appreciated by those skilled in the art. By way of example, this may be done using various approaches such as an inpainting algorithm, and, more particularly, fluid-flow modeling algorithms such as Navier-Stokes equations, etc.

Another approach is to perform exemplar inpainting, which involves "cutting" and "pasting" of patches from within the DEM **40** (or a different data set) to provide a best match for the corrupted or voided data, as will be appreciated by those skilled in the art. The inpainting may be done in an iterative fashion in some embodiments, as will also be appreciated by the skilled artisan. Further details regarding exemplary inpainting approaches which may be used are set forth in co-pending U.S. patent application Ser. Nos. 11/458,811 and 11/858,247, which are both assigned to the present Assignee and are hereby incorporated herein in their entireties by reference.

The localized error region or regions **41'** to be inpainted may be selected in various ways. In accordance with the exemplary embodiment illustrated in FIG. **8**, the localized error regions **41'** are prioritized for inpainting based upon their respective error values (Block **80'**). That is, upon calculating the errors for the localized error regions **41'**, these regions are prioritized for inpainting based thereon. For example, the errors may be sorted by maximum error, relative error, etc., and the regions **41'** are then selected for inpainting one at a time from a highest to a lowest error value, as will be appreciated by those skilled in the art. However, it should be noted that in other embodiments the order of regions **41'** to be inpainted could be selected in a different order, or more than one region could be painted at a time.

The processor **32** re-calculates the overall error value for the DEM **40'** after inpainting of the localized error region(s) **41'** to determine if the overall error value is below an error threshold, at Blocks **74-75**. If it is, then the processor **32** stops inpainting of the current localized error region **41'**, thus concluding the method illustrated in FIG. **7**, at Block **76**. Otherwise, the processor **32** returns to inpainting of the same or a different region **41'** until the overall error value is brought below the error threshold.

In one exemplary embodiment where localized error regions are inpainted one at a time from highest to lowest error value, if upon re-calculation of the overall error value the overall error value is not below the error threshold, then the processor **32** determines whether the error value for the localized error region being inpainted is below an error threshold (which may be the same or a different threshold than the overall threshold), at Block **81'**. If it is not, then the processor **32** returns to this same localized error region **41'** for

more inpainting operations. Otherwise, the processor **32** moves to the next localized error region **41'** (i.e., the one with the next highest error value in line to be inpainted), at Block **82'**.

The foregoing will be further understood with reference to the example illustrated in FIG. **4**. Here, there are seven identified error regions **41'** having error values ranging from 1.72018 m RMSE (highest) to 1.58867 m RMSE (lowest), and an overall error value for the error DEM **40'** is 1.81043 m. The error threshold selected for this example is 1.6 m, but it should be noted that other error thresholds may be used in other embodiments as appropriate. Accordingly, the processor **32** will first select the localized error region **41'** with the 1.72018 m RMSE error value for inpainting, and then inpaint this region until its error value of the DEM **41'** is less than 1.6 m RMSE, or until the overall error value is less than 1.6 m RMSE. If the former occurs before the latter, the processor **32** moves along to inpaint the next error region **41'** with the 1.67647 m RMSE, etc., until the overall error value of the error DEM **40'** is less than 1.6 m RMSE.

Another particularly advantageous feature of the system **30** is that once the localized error regions **41'** are selected, the processor **32** may optionally display the geospatial model data set along with error indicating boundaries **46** which identify errant buildings **45** or other objects/areas on the display **33**, at Block **83'**, as seen in the TIN **40**A of FIG. **5**A (without boundaries), and TIN **40**B of FIG. **5**B (with boundaries). This allows a user to better visualize exactly which buildings **45**, etc. are problem spots within the geospatial model data set. In the illustrated example, the error indicating boundaries **46** are geometric shapes. Moreover, these shapes are transparent or semi-transparent to allow the object with which the indicator is associated to still be seen therethrough. In the illustrated example, the geometric shapes are cylinders or semi-cylindrical shapes (i.e., partial cylinders), which provides a desirable visual contrast to generally rectangular buildings. However, other shapes/indicators may also be used. The indicators **46** may also be colored in certain embodiments to indicate the severity of the error (e.g., red-orange-yellow-white to indicate highest to lowest error values).

Certain advantages of the above-described system **30** and method are that they provide automated model problem area location and prioritization. In some implementations, this approach may be fully automated with no manual (i.e., user) searching required for problem areas within a geospatial model data set. Moreover, the results may helpfully be prioritized by which areas should-be addressed first.

In accordance with another aspect now described with reference to FIGS. **9-12**, a system **30'** and associated method for helping a user to more easily replace buildings **45** within localized error regions **41'** of a geospatial model data set is now described. Beginning at Block **110**, the processor **32'** cooperates with the model data storage device **31'** and display **33'** to display geospatial model data including one or more groups of data points corresponding to a respective building **45**, at Block **111**. A given group of building data points may be selected for processing, such as by automatic selection of a group of points by the processor **32'** or manual selection by a user with a user input device **34'**, which may be a mouse, joystick, keyboard, etc., as will be appreciated by those skilled in the art.

In one exemplary automated embodiment, a queue may be constructed using the above-described localized error region **41'** error value prioritization (i.e., based upon error calculation) to create a queue for buildings that need to be corrected, at Block **120'**, and the processor **32'** may take these in the order they are in the queue (e.g., from highest error value to lowest error value). The error calculations may be performed using the above-described approaches (e.g., RMSE, etc.), for example, as discussed further above. Moreover, these error calculations may also advantageously be performed on either 2D or 3D data sets, as will be appreciated by those skilled in the art. Alternatively, upon display of the error indicating boundaries/shapes **46**, a user may manually select (with the user input device **34'**) a desired group of building data points to be corrected. Other suitable selection approaches may be used as well, as will be appreciated by those skilled in the art.

It should be noted that, as used herein, "3D" is meant to cover both true three-dimensional model data as well as so-called 2½ or 2.5D model data. More specifically, many DEMS or other geospatial model data sets are sometimes referred to as "2.5D" because they include rendered building walls, etc. that are not necessarily present in the original data capture, and thus do not provide a completely accurate 3D image as it would appear to the human eye upon viewing a scene. However, for clarity of discussed "3D" is meant to cover both cases herein.

For the selected group of building data points, the processor **32'** then advantageously displays a plurality of different user-selectable building shapes **100***a*-**100***d* (FIG. **10**), at Block **112**. That is, the processor **32'** presents the user with a plurality of possible building shapes, so that the user can quickly select a shape that best fits the selected group of points. In particular, the plurality of user-selectable different building shapes **100***a*-**100***d* have different respective feature detail levels associated therewith.

Generally speaking, the user decides which building shape **100***a*-**100***d* to select based upon a tradeoff between visual resemblance and acceptable error for each building **45**, which will depend upon the particular error parameters for a given geospatial model data set, as will be appreciated by those skilled in the art. Once a desired building shape has been selected by the user (i.e., with the user input device **34'**), the processor **32'** may then advantageously replace the given group of building data points with the selected building shape, at Block **113**, and may update the data set according (i.e., save the change in the model data storage device **31'**) thus concluding the method illustrated in FIG. **11** (Block **114**).

In the illustrated example, the shape with the least or lowest feature detail level (and, correspondingly, the highest error value associated therewith) is the generally rectangular building or "bounding" box **100***a*. On the other hand, the shape **100***d* has the highest feature detail level (i.e., the lowest error value), because it is a one-to-one match of the group of building data points. That is, the shape **100***d* includes all of the detail present in the original data set. The shapes **100***b* and **100***c* have varying levels of detail between the highest and lowest levels of the shapes **100***a* and **100***d*, respectively, as seen in FIG. **10**.

The plurality of user-selectable building shapes **100***a*-**100***d* may conceptually be considered as a "toolbox" of possible building shapes from which the user can quickly select a given shape to more accurately reflect the true or "real-life" shape of the actual building **45** being rendered in the model. This toolbox of shapes **100***a*-**100***d* may be used in lieu of inpainting the building as described above. That is, using the above described approach, the processor **32'** may select groups of building data points to be corrected in order based upon error values associated therewith, and then present the user with respective building shapes for each building to replace the errant groups of data points until the overall error of the geospatial model data set falls below the error threshold (or the localized error threshold falls below the error thresh-

old). Of course, in other embodiments the user may just manually replace desired groups of building points without the use of error thresholds, if desired.

In addition, multiple levels of building shapes or toolboxes may be presented to the user. For example, the user may be presented with the first set of four building shapes **100***a*-**100***d*, and based upon the selected shape the processor **32'** may provide another set of four shapes with detail levels (or error values) closer to the first selected shape, etc. Thus, the user can "drill-down" through a plurality of shape levels to obtain a most desired match. Moreover, through each successive level of potential shapes, the processor **32'** may add further details or features to the shapes, such as roof pitches, etc. This may advantageously help conserve processing time, since the processor **32'** does not have to generate multiple shapes along a large spectrum of possible error values, but rather can quickly focus in on a narrower error range of interest to the user and only generate building shapes within this range, as will be appreciated by those skilled in the art.

Certain advantages of the system **30'** and associated methods are that they provide automated problem resolution, including a relatively full range of automatically created options (i.e., user-selectable building shapes) that are presented to a user on screen, ranging from the building box **100***a* all the way to the original point cloud **100***d*. Moreover, this approach may advantageously allow users to make customized solutions "on the fly" based on user requirements.

Turning additionally to FIGS. **13-17**, another advantageous geospatial modeling system **30"** and related method aspect are now described which allow a user to relatively quickly and easily perform manual error correction on a 3D model, rather than having to translate over to 2D image space. By way of example, the following approach may be used in combination with the above-described methods such that if a localized error region cannot be inpainted to the point where its error value is below the error threshold, or a suitable building shape cannot be presented for the user, the user can "manually" correct an errant objects such as a building. It should be noted that reference herein to a "building" is meant to include a wide range of man-made structures (e.g., houses, stadiums, arenas, storage tanks, bridges, etc.), and not just high-rise building structures, although "building" is used throughout for simplicity and clarity of reference.

More particularly, beginning at Block **170**, in the present embodiment the processor **32"** cooperates with the geospatial model data storage device **31"**, the user input device **34"**, and the display **33"** for displaying a 3D geospatial model data set on the display, at Block **171**. Moreover, a building boundary **141** is displayed around a user-selected building area in a DEM **140** responsive to the user input device **34"** (Block **172**), and a histogram of height values within the selected building area is generated, at Block **173**. In the present example, the DEM **140** is "raw" in that no error correction has yet been performed thereto.

The processor **32"** may then advantageously determine a building height based upon the histogram of height values, at Block **174**. By way of example, the building height may be based upon a peak histogram value. More particularly, the building height may be chosen as the center of a first or predominant height cluster (starting from a minimum value of the histogram) that meets a predetermined set of statistical criteria. This approach may advantageously select a building height with less susceptibility to error from noisy edge posts for data collection points around the edges of buildings, for example, as will be appreciated by those skilled in the art.

Once the building height is determined, a building shape is then generated based upon the user-selected building area **141** and the deter-mined building height, at Block **175**, and data points within the user-selected building area are replaced based upon the building shape, at Block **176**, thus concluding the illustrated method (Block **177**). That is, the processor **32"** renders a new building shape having the outline of the user-selected building area **141** and the determined building height.

In FIG. **15**, the DEM **140'** is first shown (left-hand side of drawing) after the original input was run through the LiteSite® Automated Building Vector process. The DEM **140'** includes areas with short buildings, boundary conditions/errors, occlusions, and noise, for example.

By way of comparison, a manually touched-up version of the DEM **140"** using the above-noted approach is shown on the right-hand side of FIG. **15**. This corrected DEM **140"** took approximately two minutes of user time to perform the error correction operations shown (by a trained operator), above the requisite processing (i.e., CPU) time. However, this CPU processing time is relatively insignificant compared to the processing time required for the fully automated error correction. FIGS. **16**A and **16**B are corresponding simulated 3D views **140**A' and **140**B' of the automatically corrected DEM **140'** and manually corrected DEM **140"** of FIG. **15**, respectively. As seen in the simulated views, the manual touch-up results in the generation of buildings **145**B' not included in the fully automated DEM **140'** (i.e., in addition to buildings **145**A' present therein).

Depending upon a given implementation and the particular error/accuracy requirements for a particular geospatial model data set, it may be acceptable to simply use a fully automated approach to error correction, as this provides significant improvement over the basic uncorrected DEM **140**. However, where further accuracy is required, the above-described 3D manual error correction approach (which is referred to herein as "manual" because it requires some user involvement to draw the user-selected building area **141**, although the remainder of the process may in fact be automated) may advantageously be used in place of, or as a supplement to, fully automated error correction. It is noteworthy that the above-described manual approach is much less time consuming than typical current manual model editing tools, which require translation or re-location to corresponding 2D views, user guessing of building height values, etc., which can be very time consuming for the user.

Accordingly, the system **30"** and associated methods may advantageously allow for drawing directly on a DEM, etc., as an additional quality control option. This approach does not require user involvement to obtain the height of a manually drawn building, i.e., the processor **32"** advantageously does this for the user in an automated fashion based upon the user-selected building area **141**. As such, time-consuming relocation to 2D images need not be performed, as with many prior art image-based error correction techniques. Moreover, since problem areas may be corrected directly on the displayed 3D DEM or other 3D data model, additional satellite or aerial reference imagery need not be required, which can provide additional time and cost savings.

Other advantages of the above-described systems and methods may include: savings of time and cost in the quality control phase of 3D modeling production; making automated 3D model creation more flexible and verifiable to a given set of model requirements; potentially decreasing the chance of sending out a final product with a problem area overlooked; and decreasing re-work of generated models.

The above-noted geospatial model method aspects may also be embodied in a computer-readable medium having

computer-executable instructions for causing a computer to perform the steps set forth above, as will be appreciated by those skilled in the art.

Additional features of the invention may be found in co-pending applications entitled GEOSPATIAL MODELING SYSTEM PROVIDING USER-SELECTABLE BUILDING SHAPE OPTIONS AND RELATED METHODS, Ser. No. 11/863,406; and GEOSPATIAL MODELING SYSTEM PROVIDING BUILDING GENERATION BASED UPON USER INPUT ON 3D MODEL AND RELATED METHODS, Ser. No. 11/863,417, the entire disclosures of which are hereby incorporated herein by reference.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A geospatial modeling system comprising:

a geospatial model data storage device containing a geospatial model data set representing latitude, longitude, and elevation data; and

a processor cooperating with said geospatial model data storage device and configured to

identify a plurality of localized error regions within the geospatial model data set and calculate respective localized mean square error (MSE) values associated with each localized error region,

calculate an overall MSE value for the geospatial model data set based upon the plurality of localized error regions,

prioritize the localized error regions from highest to lowest localized MSE values and iteratively inpaint the localized error region having the highest localized MSE value until the localized MSE value is below an error threshold,

re-calculate the overall MSE value, and

stop inpainting when the re-calculated overall MSE value is below the error threshold and, if the re-calculated overall MSE value is not below the error threshold, then iteratively inpaint the localized error region with the next highest localized MSE value.

2. The geospatial modeling system of claim **1** further comprising a display; and wherein said processor is configured to cooperate with said geospatial model data storage device and said display to display the geospatial model data set along with error indicating boundaries indicating the localized error regions.

3. The geospatial modeling system of claim **2** wherein said error indicating boundaries comprise colored transparent geometric shapes.

4. The geospatial modeling system of claim **1** wherein each localized MSE value comprises a localized root mean square error (RMSE) value; and wherein the overall MSE value comprises an overall root mean square error (RMSE) value.

5. The geospatial modeling system of claim **1** wherein said processor is configured to inpaint by iteratively propagating contour data from outside the at least one localized error region into the at least one localized error region.

6. The geospatial modeling system of claim **5** wherein said processor is configured to inpaint by iteratively propagating the contour data from outside the at least one localized error region into the at least one localized error region based upon at least one turbulent fluid flow modeling equation.

7. The geospatial modeling system of claim **5** wherein said processor is configured to inpaint by iteratively propagating the contour data from outside the at least one localized error region into the at least one localized error region based upon exemplar inpainting.

8. A geospatial modeling system comprising:

a geospatial model data storage device containing a geospatial model data set representing latitude, longitude, and elevation data;

a display; and

a processor cooperating with said geospatial model data storage device and said display and configured to

identify a plurality of localized error regions within the geospatial model data set,

calculate respective localized root mean square error (RMSE) values associated with each localized error region, and prioritize the localized error regions for inpainting based upon their respective localized RMSE values,

calculate an overall RMSE value for the geospatial model data set based upon the plurality of localized error regions,

iteratively inpaint the localized error region having the highest localized RMSE value until the localized RMSE value is below an error threshold,

re-calculate the overall RMSE value, and stop inpainting when the re-calculated overall RMSE value is below the error threshold and, if the re-calculated overall RMSE value is not below the error threshold, then iteratively inpaint the localized error region with the next highest localized RMSE value, and

display the geospatial model data set along with error indicating boundaries indicating the localized error regions.

9. The geospatial modeling system of claim **8** further comprising a display; and wherein said processor is configured to cooperate with said geospatial model data storage device and said display to display the geospatial model data set along with error indicating boundaries indicating the localized error regions.

10. A geospatial modeling method comprising:

using a processor and a geospatial model data storage devices coupled thereto to

identify a plurality of localized error regions within a geospatial model data set and calculate respective localized mean square error (MSE) values associated with each localized error region, the geospatial model data set representing latitude, longitude, and elevation data;

calculate an overall MSE value for the geospatial model data set based upon the plurality of localized error regions;

prioritize the localized error regions from highest to lowest localized MSE values and iteratively inpaint the localized error region having the highest localized MSE value until the localized MSE value is below an error threshold;

re-calculate the overall MSE value; and

stop inpainting when the re-calculated overall MSE value is below the error threshold and, if the overall re-calculated MSE value is not below the error threshold, then iteratively inpaint the localized error region with the next highest localized MSE value.

11. The method of claim **10** wherein each localized MSE value comprises a localized root mean square error (RMSE) value; and wherein the overall MSE value comprises an overall root mean square error (RMSE) value.

12. The method of claim 10 further comprising displaying the geospatial model data set on a display along with error indicating boundaries indicating the localized error regions.

13. A non-transitory computer-readable medium having computer-executable instructions for causing a computer to perform steps comprising:

identifying a plurality of localized error regions within a geospatial model data set and calculating respective localized mean square error (MSE) values associated with each localized error region, the geospatial model data set representing latitude, longitude, and elevation data;

calculating an overall MSE value for the geospatial model data set based upon the plurality of localized error regions;

prioritizing the localized error regions from highest to lowest localized MSE values and iteratively inpainting the localized error region having the highest localized MSE value until the localized MSE value is below an error threshold;

re-calculating the overall MSE value; and

stopping inpainting when the overall re-calculated MSE value is below the error threshold and, if the overall re-calculated MSE value is not below the error threshold, then iteratively inpainting the localized error region with the next highest localized MSE value.

14. The non-transitory computer-readable medium of claim 13 wherein each localized MSE value comprises a localized root mean square error (RMSE) value; and wherein the overall MSE value comprises an overall root mean square error (RMSE) value.

15. The non-transitory computer-readable medium of claim 13 further having computer-executable instructions for causing the computer to perform a step comprising displaying the geospatial model data set on a display along with error indicating boundaries indicating the localized error regions.

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